

FINAL Report

**NASA Award NAG3-2837
(SU account #3534176)**

Workshop on Transition and Unsteady Aspects of Turbomachinery Flows

**John E. LaGraff
Principal Investigator
Syracuse University
Syracuse University, New York 13244**

Jan 2004

Workshop on Transition and Unsteady Aspects of Turbomachinery Flows

John E. LaGraff
Principal Investigator
Syracuse University
Syracuse, New York 13244

Abstract

A workshop was organized on the topic of the title and held on August 17-20, 2003 at the Syracuse University Minnowbrook Conference Center in Blue Mountain Lake, New York. Attendance was by invitation only, forty-seven guests attended and thirty presentations were made. Support was received from NASA Glenn Research Center, the US Air Force Office of Scientific Research, the European Office of Aeronautical Research and Development, the Asian Office of Aeronautical Research and Development and Syracuse University. This workshop was the fourth in a triennial series beginning in 1993. A publication under a NASA CP 2004-212913 will be issued and include all abstracts. No full written papers were required. This report includes a list of attendees and the program of presentations. The next workshop is scheduled for August 20-23, 2006.

Minnowbrook IV
August 2003
List of Participants

Reza Abhari

ETH/Zurich
Turbomachinery Lab
rabhari@ethz.ch

Rich Anthony

Air Force Research Laboratory
Propulsion Directorate
Richard.Anthony@wpafb.af.mil

Tom Beutner

AFOSR/NA
Turbulence and Rotating Flows
tom.beutner@afosr.af.mil

Elena Bogdanova-Ryzhova

GE Global Research
Fluid Mechanics Laboratory
ryzhov@crd.ge.com

Robert Boyle

NASA Glenn Research Ctr.
Turbine Branch
aeboyle@jimbob.grc.nasa.gov

Dave Car

Air Force Research Laboratory
Propulsion Directorate
david.car@wpafb.af.mil

John Clark

Air Force Research Laboratory
Turbine Engine Division
John.Clark3@wpafb.af.mil

Tom Corke

University of Notre Dame
Aerospace & Mechanical Engr.
Dept.
corke.2@nd.edu

Jeffrey Crouch

Boeing
Commercial Airline Group
jeffrey.d.crouch@boeing.com

Erik Dick

University of Ghent
Dept. of Mechanical & Thermal
Engineering
erik.dick@rug.ac.be

Michael Dunn

Ohio State University
Mechanical Engineering/Gas
Turbine Lab
dunn.129@osu.edu

Paul Durbin

Stanford University
Dept. of Mechanical Engineering
durbin@vk.stanford.edu

Karl Engel

MTU Aero Engines GmbH
Compressor Aerodynamics TPAV
Karl.Engel@muc.mtu.de

Hermann Fasel

University of Arizona
Aerospace & Mechanical
Engineering
faselh@u.arizona.edu

Torsten Fransson

EKV/KTH
Department of Energy Technology
fransson@egi.kth.se

Simon Gallimore

Rolls Royce Plc
Turbine Thermofluid Systems
Engineering
simon.gallimore@rolls-royce.com

Jochen Gier

MTU Aero Engines GmbH
Tubinaerodynamik
jochen.gier@muc.mtu.de

Paul Gostelow

University Of Leicester
Dept. Of Engineering
jpg7@leicester.ac.uk

Brent Gregory

Alstom Power
Aerodynamics
brent.gregory@power.alstom.com

Greg Heitland

Honeywell Engines
Turbomachinery Aerodynamics
greg.heitland@honeywell.com

Howard Hodson

Cambridge University
Whittle Lab
hph@eng.cam.ac.uk

Jean Hourmouziadis

Technische Universitat Berlin
Institut fur Luft-und Raumfahrt F1
hourmouziadis@tu-berlin.de

George Huang

University of Kentucky
Department of Mechanical
Engineering
ghuang@engr.uky.edu

Lennert Hultgren

NASA Glenn Research Ctr.
Turbine Branch
hultgren@grc.nasa.gov

Mark Johnson

University of Liverpool
Dept. of Mechanical Engr.
em22@liverpool.ac.uk

John E. LaGraff

Syracuse University
Mech., Aero., & Mfg. Engr.
jlagraff@syr.edu

Roddam Narasimha
Indian Inst. of Science
Director, National Institute of Adv.
Studies
roddam@caos.iisc.ernet.in

Ted Okiishi
Iowa State University
College of Engineering
tedo@iastat.edu

Lou Povinelli
NASA Glenn Research Center
Turbomachinery and Prop Systems
louis.a.povinelli@grc.nasa.gov

Thomas Praisner
Pratt & Whitney Company
Turbine Aerodynamics
thomas.praisner@pw.utc.com

Eli Reshotko
Case Western Reserve Univ.
Dept. of Mech. & Aero. Eng.
exr3@po.cwru.edu

Wolfgang Rodi
Karlsruhe Universitat
rodi@ifh.uni-karlsruhe.de

Oleg Ryzhov
UC Davis
Mech & Aero Engineering
oryzhov@nycap.rr.com

Jayant Sabnis
Pratt and Whitney Company
Aerodynamics Dept
sabnisjs@pweh.com

Mehmet Sarimurat
Syracuse University
Department of Mechanical,
Aerospace Engineering
mnsarimu@syr.edu

Avi Seifert
Tel Aviv University
Ramat-Aviv
seifert@eng.tau.ac.il

Joerge Seume
University of Hannover
Institute for Turbomachinery
seume@ifs.uni-hannover.de

Om Sharma
Pratt and Whitney Company
sharmaop@pweh.com

Frank Smith
University College-London
Dept. of Mathematics
frank@math.ucl.ac.uk
Frank.Smith@ukgateway.net

Vassilis Theofilis
Nu-Modeling, Inc.
vassilios.theofilis@nu-
modelling.com

Kenneth Van Treuren
Baylor University
Department of Engineering
kenneth_van_treuren@baylor.edu

Ralph Volino
U.S. Naval Academy
Department of Mechanical
Engineering
volino@usna.edu

Aspi Wadia
General Electric Co.
Compressor, Turbine
Aerodynamics & Operability
aspi.wadia@ae.ge.com

Greg Walker
Univ. of Tasmania
School of Engineering
greg.walker@utas.edu.au

Ed White
Case Western Reserve Univ.
Dept. of Mech and Aerospace
Engineering
ebw@po.cwru.edu

Israel Wagnanski
University of Arizona
Aerospace & Mechanical
Engineering
wagnanski@ame.arizona.edu

PROGRAM

MINNOWBROOK IV

TRANSITION AND UNSTEADY ASPECTS OF TURBOMACHINERY FLOWS

17-20 AUGUST 2003

Sunday - 17 August 2003

- 3.00 pm Minnowbrook Center Open to Participants / Registration Begins
- 3.30-5.30 pm Visit to Adirondack Museum (optional)
- 6.00 pm Dinner
- 8.00 pm Welcome-
Organization, Goals and Focus of Workshop
John LaGraff - Syracuse University
- 8.15 pm Louis Povinelli - Keynote Speaker (30 minutes) - NASA Glenn
Current Issues in Unsteady Turbomachinery Flows
- 9.00 pm Social get together

Monday - 18 August 2003

- 7.00 am Breakfast
- Session 1 - Industry Panel**
Moderator: Reza Abhari - ETH, Zurich
- 8.00 am **Industry Panel:**
Simon Gallimore – Rolls-Royce
Jochen Gier - MTU
Brent Gregory – Alstom
Greg Heitland- Honeywell
Om Sharma – Pratt and Whitney
Aspi Wadi – General Electric
- 10.15 am BREAK

Session 2 - Turbines

Moderator: Jayant Sabnis – Pratt and Whitney

- 10.45 am Vassilis Theofilis - Nu-Modeling Inc.
On 2D Basic States in LPT Flows and their 3D Instability
- 11.00 am Reza Abhari - ETH, Zurich
Influence of End Wall Leakage On Secondary Flow Development in Axial Turbines
- 11.15 am Ralph Volino - US Naval Academy
Active and Passive Flow Control on Low Pressure Turbine Airfoils
- 11.30 am George Huang - University of Kentucky
Experimental and Numerical Investigation of Transitional Flows as Affected by Passing Wakes/ Using Experimental Data from a Transitional Boundary Layer Experiment to Discuss Transition Modelling: with Application to the Low-pressure Turbine (Terry Simon material)
- 11.45 am Discussion
- 12.30 pm LUNCH

Session 3 - Blade Cooling, Heat Transfer and By-Pass Transition

Moderator: Jochen Gier- MTU

- 2.00 pm Robert Boyle - NASA Glenn
Effects of Free-Stream Turbulence on Turbine Blade Heat Transfer
- 2.15 pm Paul Durbin - Stanford University
Bypass Transition Via Continuous Modes: Unsteady Effects on Film Cooling
- 2.30 pm Richard Anthony – AFRL Wright-Patterson AFB
High Frequency Surface Heat Flux Imaging of Bypass Transition
- 2.45 pm Oleg Ryzhov - UC Davis
Skin Friction and Heat Flux Oscillations in Upstream Moving Wave Packets
- 3.00 pm Discussion
- 3.45 pm BREAK

Session 4 - Roughness and Receptivity

Moderator: Simon Gallimore – Rolls-Royce

- 4:00 pm Howard Hodson - Cambridge University
Transition Mechanisms and Use of Surface Roughness to Enhance the Benefits of Wake Passing in LP Turbines
- 4:15 pm Eli Reshotko - Case Western Reserve University
Transient Growth Approach to Roughness-Induced Transition
- 4:30 pm Ed White - Case Western Reserve University
Roughness and Freestream Turbulence-Induced Transient Growth as a Bypass Transition Mechanism
- 4:45 pm Mark Johnson - University of Liverpool
Receptivity Calculations for Transition Prediction
- 5:00 pm Discussion
- 6:30 pm DINNER
- 8:00 pm **Session 5 - Working Group Meeting 1**

Tuesday - 19 August 2003

- 7:00 am Breakfast

Session 6 - Flow Control

Moderator: David Ashpis - NASA Glenn

- 8:00 am Israel Wygnanski-Univ of Arizona
On Streamwise Vortices on a Curved Wall
- 8:15 am Tom Corke - University of Notre Dame
Plasma Actuators for Separation Control of Low Pressure Turbine Blades
- 8:30 am Lennert Hultgren - NASA Glenn
Boundary Layer Separation Control under Low-Pressure Turbine Airfoil Conditions Using Glow Discharge Plasma Actuators
- 8:45 am Hermann Fasel - University of Arizona
Numeric Simulation of Active Flow Control for Low Pressure Turbine Blades
- 9:00 am Discussion

9.45 am BREAK

Session 7 - Separation Bubbles, Calmed Regions and Spots

Moderator: Israel Wygnanski – University of Arizona

10.15 am Avi Seifert - Tel Aviv University
Effect of Elevated Free-Stream Turbulence on Active Control of a Separation Bubble

10.30 am Paul Gostelow - University of Leicester
Wakes, Calming and Transition Under Strong Adverse Pressure Gradients

10.45 am Jean Hourmouziadis - Technische Universitat Berlin
Phase Shift of Separation Bubble Transition in Unsteady Flow

11.00 am Frank Smith - University College, London
Modelling Spots: The Calmed Region, Pressure Gradient Effects and Background

11.15 am Discussion

12.00 pm LUNCH

Session 8 - Compressor Stall, Unsteady Interactions and Low Reynolds Numbers

Moderator: Aspi Wadia – General Electric

1.30 pm Greg Walker- University of Tasmania
Modelling of Unsteady Transitional Flow on Axial Compressor Blades

1.45 pm Thomas Praisner – Pratt & Whitney
Challenges in Predicting Component Efficiencies in Turbomachinery with Low Reynolds Number Blading

2.00 pm Jorge Seume - University of Hanover
Observations on the Causal Relationship Between Blade Count and Developing Rotating Stall in a Four Stage Axial Compressor

2.15 pm Torsten Fransson - EKV/KTH, Stockholm
Experimental and Numerical Study of Non-Linear Interactions in Transonic Nozzle Flow

2.30 pm Mike Dunn- Ohio State University
Influence of Clocking and Vane/Blade Spacing on Unsteady Surface Pressure

2.45 pm Discussion

- 3:30 pm BREAK
- Session 9 - Transition Calculations and Turbulence Modelling**
Moderator: Greg Heitland - Honeywell
- 4.00 pm Wolfgang Rodi - Karlsruhe Universitat
DNS and LES of Transition on Turbine Blades
- 4.15 pm Roddam Narasimha – Indian Institute of Science
Review of Recent Research in Bangalore on the Transition Zone
- 4.30 pm Jeffrey Crouch - Boeing Commercial Aircraft Group
Predicting Unsteady Buffet Onset Using RANS Solutions
- 4.45 pm Eric Dick - University of Ghent
Transition Modeling with a Dynamic Intermittency Transport Equation
- 5.00 pm Discussion
- 5.45 PM **Session 10 - Working Group Meeting 2**
- 7.00 pm DINNER
- 8.30 pm **Session 11 - Working Group Meeting 3**

Wednesday - 20 August 2003

- 7.00 am Breakfast
- Session 12 - Wrap-up Session**
Moderator: Paul Gostelow - University of Leicester
- 8.00 am Report of ad-hoc working groups
Ted Okiishi – Iowa State University
- 8.45 am Report of Industry Panel Group (Group Spokesman TBA)
- 9:15 am Wrap-up discussions/Observations
Roddam Narasimha – Indian Institute of Science
- 9.45 am John LaGraff – Syracuse University
Conclusion of workshop
- 10.00 am First van leaves for Syracuse Airport

10.30 am Second van leaves for Syracuse Airport

11.30 am Box lunches for remaining participants

12 noon All must vacate center.